Resonantly hybridized excitons in moiré superlattices in van der Waals heterostructures

Alexander Tartakovskii

Department of Physics and Astronomy, University of Sheffield, UK

a.tartakovskii@sheffield.ac.uk

Recent years have seen significant effort in exploration of monolayer semiconductors such as transition metal dichalcogenides (TMDs) MoS$_2$, WS$_2$, MoSe$_2$, WSe$_2$ etc. Of particular interest is a possibility to combine few-atomic-layer crystals to create artificial heterostructures with tailored electronic and optical properties. This route opens possibilities inaccessible for traditional semiconductors, where the strict lattice matching requirement limits possible combinations of materials in a heterostructure. In contrast, atomically-thin layers of two-dimensional materials can be assembled in vertical stacks held together by relatively weak van der Waals forces, allowing for coupling between monolayer crystals with incommensurate lattices and arbitrary mutual rotation. The lattice constant difference and the mutual rotation angle present new degrees of freedom for the design of novel meta-materials. A profound consequence of using these new degrees of freedom is the emergence of an overarching periodicity in the local atomic registry of the constituent crystal structures, known as a moiré superlattice. Its presence in graphene/hexagonal boron nitride structures led to observation of the Hofstadter butterfly spectra, and recently culminated in the discovery of the intriguing superconductor-insulator transition at magic twist angles. We show that in semiconducting heterostructures built of incommensurate MoSe$_2$ and WS$_2$ monolayers, excitonic bands can hybridize, which results in the resonant enhancement of the moiré superlattice effects. MoSe$_2$ and WS$_2$ are specifically chosen for the near degeneracy of their conduction band edges to promote the hybridization of intra- and interlayer excitons. For MoSe$_2$/WS$_2$ heterostructures with almost aligned pairs of monolayer crystals, the resonant mixing of the electron states leads to amplified effects of the heterostructure’s geometrical moiré pattern on the hX dispersion.